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ES&H Section

RP. NOTE 143

Dose from Survey Hole in the NuMI Target Chase Iron shielding

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Introduction

In order to check the alignment of the NuMI horns, provisions are made to put 2.5-inch diameter penetrations in the steel shielding on top of the horns (Figs.1-3). There are survey Balls (Tooling balls) attached to the sides of the horn end flanges[1], which should be reachable by a long survey tool, to check the alignment of the horn. After 30 days of irradiation, shielding and equipment inside the target chase will be highly radioactive. Residual dose rates will be in hundreds of rad/hr. This note presents calculations used to estimate the dose to the hand of a surveyor placed on the top end of the hole. Mitigations using time and shielding is suggested.

Assumptions

The following list describes the data and the information used for the calculations.

- Since the first horn is irradiated more than the second horn, only horn 1 parameters were used[1-3].
- The dose rate information was taken from a MARS calculation paper[1] that was provided at the July 17, 2003 Radiation Safety review[4].
- The one-year irradiation and one week cooling values were used for this note. This irradiation time is conservative and the cooling time is reasonable given the preparatory work required to get to the horn alignment phase.
- The radioactivation level at the bottom of the module is the same as the bottom of the chase; residual dose rate is 201 rad/hr.
- Survey ball is at the same activation level as the horn 1 downstream flange; residual dose rate is 191 rad/hr (The rates are almost the same, as expected.)
- The residual dose rate at the top of the module is 0.6 mrad/hr
- From the information provided[5] the depth of the hole (L) is estimated to be 6 feet.
- Distance of survey ball to the bottom of the module is 15.5 inches (L_{ball}).
- Distance of survey ball to the bottom of the chase is 37 inches ($L_{chase\ bottom}$).

Calculations

The dose rate at the top of the module, due to residual activity in the module, is orders of magnitude lower than that at the bottom of the module. Since the star density distribution in the shielding material is approximately an exponential function of the thickness, an exponential fit to the two dose rates at the two ends of the module was used to describe the dose rate along the cylindrical hole. The fit was only used for interpolations.

$$\dot{D}(\ell) = \left(6.0\times10^{-4}\right)e^{0.18\ell}, \quad \text{rad/hr} \qquad (1)$$

where ℓ is the depth in inches, as measured from the top of the hole.

In order to account for the gamma rays clipping at the edge of the hole, an effective diameter, which is larger than the actual diameter was calculated using 1 MeV gamma rays attenuation length in steel. The radius of the effective area (circle) was calculated by taking an average distance (ℓ /2) and calculating the radius, such that the path of a ray originating in the middle of the hole will pass (clip) through iron a distance equal to one attenuation length. The effective radius is about 3% larger than the physical radius of the hole.

There are three sources of residual activity that contribute to the dose rate at the top of the hole; radiation from the floor of the target chase, radiation from the survey ball, and the radiation from the different parts of the activated hole wall coming through. Because of the very small aspect ratio of the hole (r/L <0.02), even single reflections from the walls of the hole are a few orders of magnitude less than the direct component[6]. Therefore, only the direct line of sight component was calculated.

For the floor and survey ball components of the radiation, a two-step method was used. First, the dose from the source at the bottom opening of the hole was calculated.

$$D' = \frac{A}{4\pi}\left(\frac{D_{0-ball}}{L_{ball}^2} + \frac{D_{0-chasebotton}}{L_{chasebottom}^2}\right). \quad (2)$$

Where A is the effective area of the opening, and L_{ball} and $L_{chase\ bottom}$ are defined in the assumptions section. Second, the direct component of the source at the top of the module was calculated as the dose from a disk source of effective radius R and contact dose D', at a distance L,

$$D = \frac{D'}{2}\ln(\sec\theta), \quad (3)$$

where θ is the angle between the cylindrical axis and the line connecting the point of the observation to the edge of the disk.

For the radiation component due to the cylindrical hole, it is noted that the dose rate calculated using MARS is the net dose rates due to the volume activation of the module and not just the activity on the surface. Therefore, the hole was modeled as a cylindrical surface source, with the activity given by Eq.1. The dose on the long axis of the cylindrical surface source simplifies to[6]

$$\dot{D} = \frac{\dot{D}_0(\ell)}{2}\tan^{-1}\left(\frac{H}{R}\right), \quad (4)$$

where $\dot{D}_0(\ell)$ is the contact dose rate, H is the height of the cylinder and R is the radius. Since the dose rate varies along the length of the cylinder, the dose at the top of the hole was calculated by summing the dose due to smaller cylinders stacked on top of each other. The dose rate at the surveyor location due to an activated cylindrical ring of length Δh_i located a distance h_i down the hole was calculated by the subtraction method (Fig. 4 and Eq. 5). It was assumed that the whole cylinder has a uniform activity the same the ring. Then the dose rate at P due to the cylindrical surface source of length (h_i- Δh_i) was subtracted from the dose rate at P due to a cylinder of height h_i,

$$\dot{D} = \frac{\dot{D}_\circ(h_i)}{2}\sum_i\left[\tan^{-1}\left(\frac{h_i}{R}\right) - \tan^{-1}\left(\frac{h_i - \Delta h_i}{R}\right)\right]. \qquad (5)$$

Some preliminary calculations showed that a reasonable length increment was half inch, since the change in dose rate from the neighboring ring was ~8%. The difference in results between using one-inch long rings and half-inch long rings is only 4%.

Results

Using the above data, a hand in contact with the hole opening on the top will receive ~188±15% mrem/hr effective dose. About 99% of this dose is due to the activated surface of the cylindrical hole. The indicated uncertainty is due only to the different methods used to calculate the dose from the hole. This is a large dose to the surveyor's hand. To reduce this dose, time, distance and shielding should be used. The results of the effects of different thicknesses of lead shield are shown in Table 1. As the last two columns of Table 1 show, two more factors were taken into consideration; the maximum dose allowed to the extremities is a factor of ten larger than that for the whole body[7] (i.e. a weighting factor of 0.1 is used for extremities when included in the whole body dose). The surveyor will spend a maximum of 10 minutes working near the hole.[5]

Table 1. Expected dose rates from horn 1.

Lead shield (in)	Build Up	Attenuation	Dose (mrem/hr)	10min Dose (mrem)	10 min Hand dose scaled to whole-body (mrem)
0.25	1.46	8.77E-01	1.65E+02	27.49	2.75
0.50	1.71	6.16E-01	1.16E+02	19.32	1.93
0.75	1.96	4.23E-01	7.95E+01	13.26	1.33
1.00	2.21	2.85E-01	5.36E+01	8.93	0.89

Conclusion

The calculation is based on the highest residual dose rate possible. However, changing a hot horn would happen only if one becomes inoperable, which may not be at the time of its highest radioactivation level. Note also the calculations are for a hand resting at the hole for 10 minutes, while the hand will rarely come that close to the hole during the insertion of the survey pole. The surveyor will be required to wear a ring badge and use a lead shield or lead clad gloves to minimize the dose.

References

1. NuMI technical design Handbook, chapter 4.2.9, also at
    a. http://www-numi.fnal.gov:8875/numwork/tdh/TDH_V3_4.2.9-module.doc

2. I. Tropin, et al., "Detailed MARS14 Simulation of the NuMI Target Hall Shielding Near Horn 1", to be published, Jan. 2002.

3. NuMI parameter Book,
   http://www-numi.fnal.gov:8875/numwork/design_params.txt

4. http://www-numi.fnal.gov/numwork/reviews/july_17.html
    i. http://www-numi.fnal.gov/numwork/reviews/aug_03.html

5. Private communication with Jim Hylen Oct. 2002.

6. A. B. Chilton, J. K. Shultis, and R. E. Faw, *Principles of radiation shielding* (Prentice-Hall, Englewood Cliffs, New Jersey, 1984).

7. Fermilab Radiation Control Manual (FRCM)
    a. http://www-esh.fnal.gov/pls/default/esh_home_page.page?this_page=900

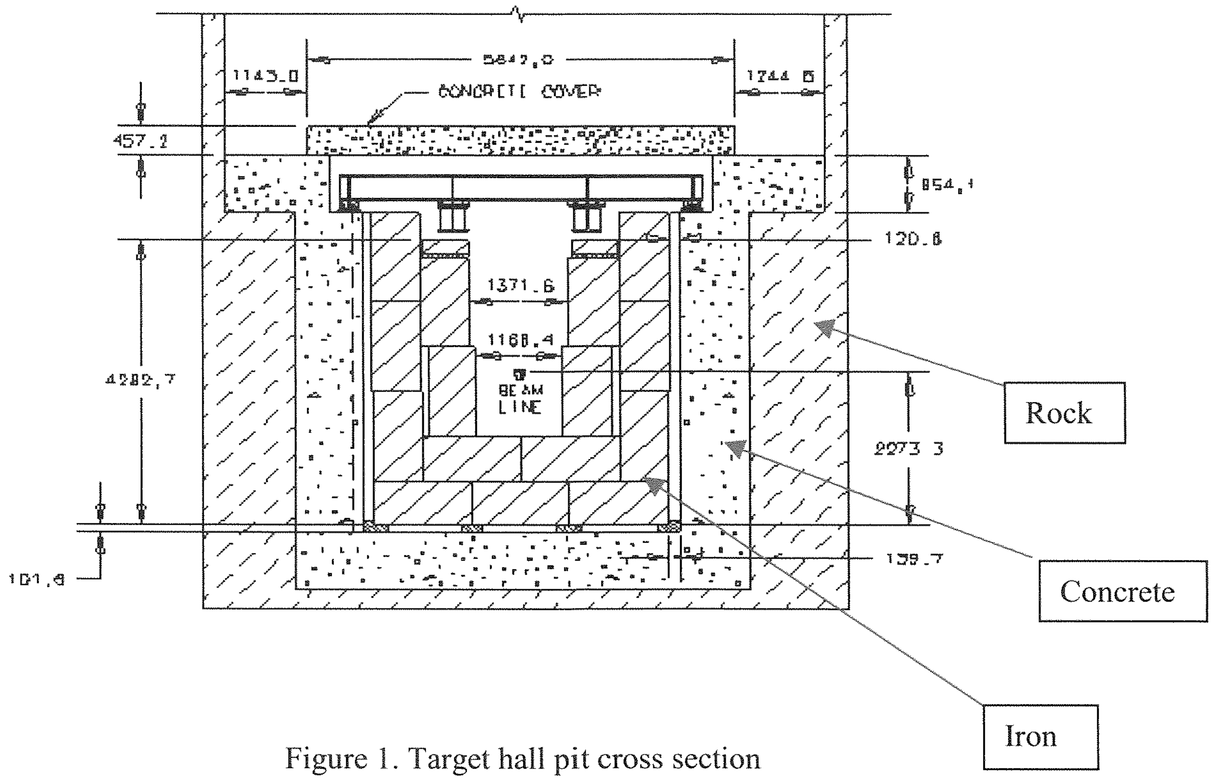

Figure 1. Target hall pit cross section

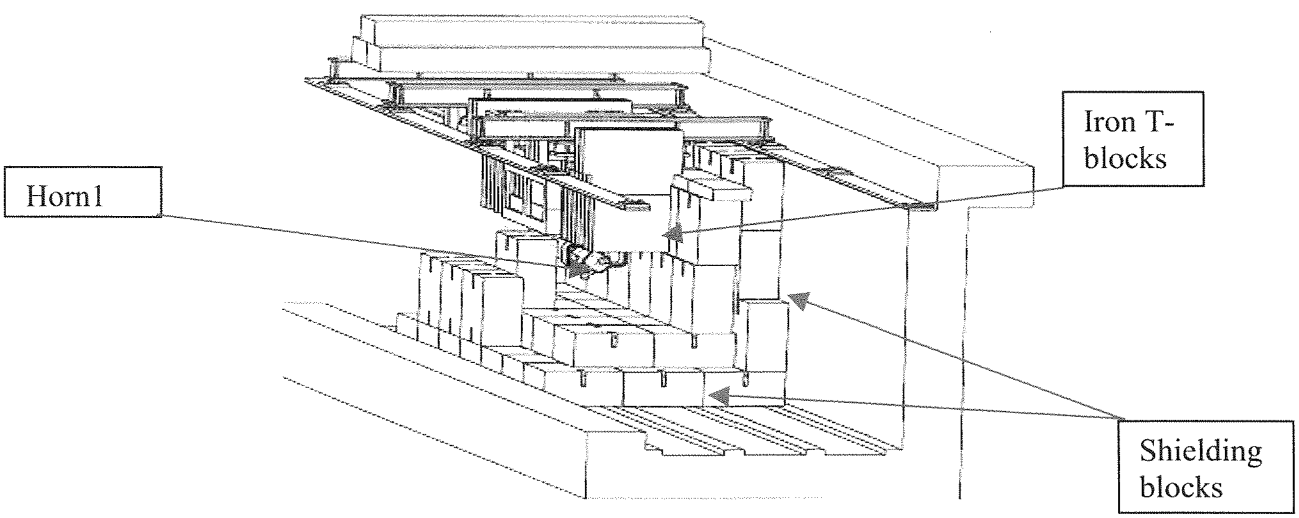

Figure 2. Schematic representation of the NuMI target chase showing the Horn 1 module and its T-blocks.

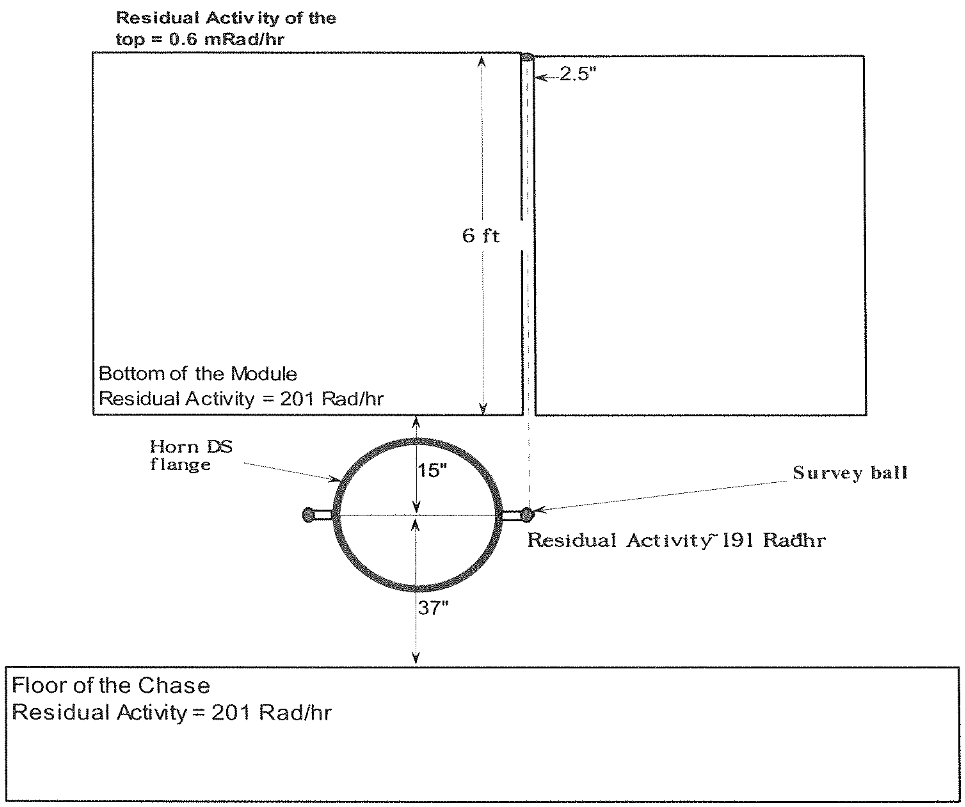

Figure 3. Schematic drawing of the setup used for the calculations.

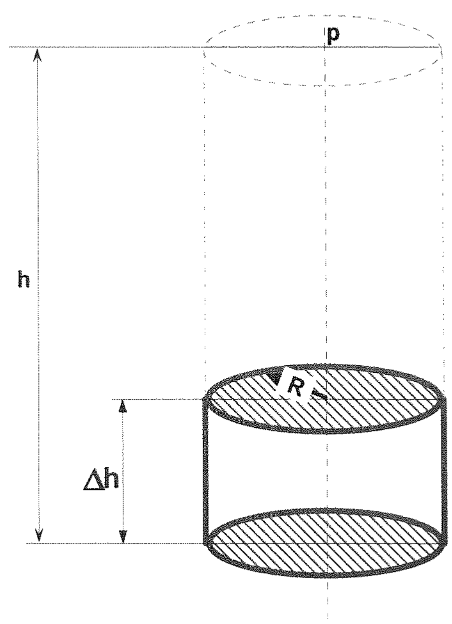

Figure 4. Schematic drawing showing the subtraction method used to calculate the dose rate at P due to an activated cylindrical ring.